CO2RE THE GREENHOUSE GAS REMOVAL HUB

Towards responsible innovation and societal engagement with carbon dioxide removal

September 2025

Rob Bellamy, Laurie Waller and Emily Cox.

Summary

- **It is imperative that carbon dioxide removal (CDR) research and development be societally responsible**. This means that those undertaking CDR research and development must anticipate risks, reflect on their assumptions, engage society in decision-making, and act upon any lessons they learn in order to positively affect the course of CDR innovation.
- Nationally representative surveys allowing people to appraise different kinds of CDR show that **the public supports the inclusion of CDR in UK climate policy**. However, respondents appraise some CDR methods less highly than others. Societal engagement will be particularly important for these.
- Regional differences in how people appraise various methods of CDR show that certain UK regions could be more or less likely to support or oppose the deployment of certain types of CDR. This makes it important to **match different types of CDR with the locations where they have the most favourable public appraisals**.
- According to our research, people see CDR as placing more of the burden of responsibility for decarbonisation onto government and industry, rather than individuals. However, they are **cautious about biochar, perennial biomass crops and peatland restoration,** and question whether these methods and their trade-offs would be "worth it".
- Going forward, field trials will have significant consequences for public engagement with carbon removal. While they are unlikely to settle controversy, **field trials are crucial to understanding emerging public concerns and studying changing perceptions**.
- Consultative approaches are unlikely to anticipate uncertainties that field trials will introduce into the everyday life and environments of communities. Public engagement must also **explore disagreements over local impacts and link trials with (existing) local climate action**.
- **The way people understand CDR depends on framing.** Communicating it requires careful use of analogies that avoid the 'nature-based' label. Communicators should explain that CDR can only help on the margins of substantial emissions reductions, and explore the different ways in which it could be implemented.
- Specifically, **framing CDR methods as 'nature-based' or 'engineered' is problematic** because where the lines are drawn on what constitutes such methods is arbitrary, privileging certain methods for no substantive reason and diverting attention away from their actual qualities.
- **The popularity of forestation is harming support for other CDR methods**. We should query the way in which tree-planting is often conflated with climate action, and instead focus on its other benefits, such as biodiversity support.
- In survey experiments, respondents **rejected business-as-usual (liberal market, top down) scenarios of CDR implementation** in favour of a bottom-up, planned economy scenario for ocean alkalinity enhancement, and a variety of alternative implementation contexts for direct air carbon capture and storage.

Why pursue responsible innovation and societal engagement with CDR?

Researchers, industry and policy-makers are considering carbon dioxide removal (CDR) methods as a way of accelerating the near-term mitigation of climate change, balancing residual emissions from hard-to-abate sectors, and addressing potential overshoot of climate targets such as the 1.5°C limit set out in the Paris Agreement. But, in many cases, CDR methods are at an early stage of research and development and raise societal concerns about effectiveness, feasibility, impacts, costs, politics, safety, acceptability and ethics. It is therefore crucial that CDR research and development is done in a way that is responsible towards society. Anyone undertaking it must anticipate the potential consequences, reflect on their assumptions, engage society in decision-making, and act on any lessons learned in order to positively affect the course of CDR innovation.

Responsible innovation and societal engagement involves members of the public in considerations about things that concern their interests. This helps strengthen accountability and transparency of CDR through learning from citizens, and can help to strengthen trust and legitimacy by building relationships between citizens, government and non-government actors. More broadly, it helps to build public engagement with climate change, which may help us to develop more effective communication approaches and detect emerging policy issues.

The following sections draw on evidence from the responsible innovation and societal engagement research taking place in CO_2RE, focusing on the UK context to answer key questions for policy-makers about how CDR can be better understood, appraised, communicated and governed.

This briefing has four sections. It starts by presenting the findings from UK national and regional societal appraisals of CDR and specific CDR methods. It then discusses a number of aspects that will be important in shaping societal engagement and support for CDR going forward, including:

1. The role of field trials and demonstrations in informing deployment of CDR and considerations for their design.
2. Considerations for effective communication of CDR and the importance of avoiding 'nature-based' versus 'engineered' framings.
3. Insights into public preferences for alternative governance scenarios for the deployment of CDR and lessons for deploying socially robust novel biological CDR techniques.

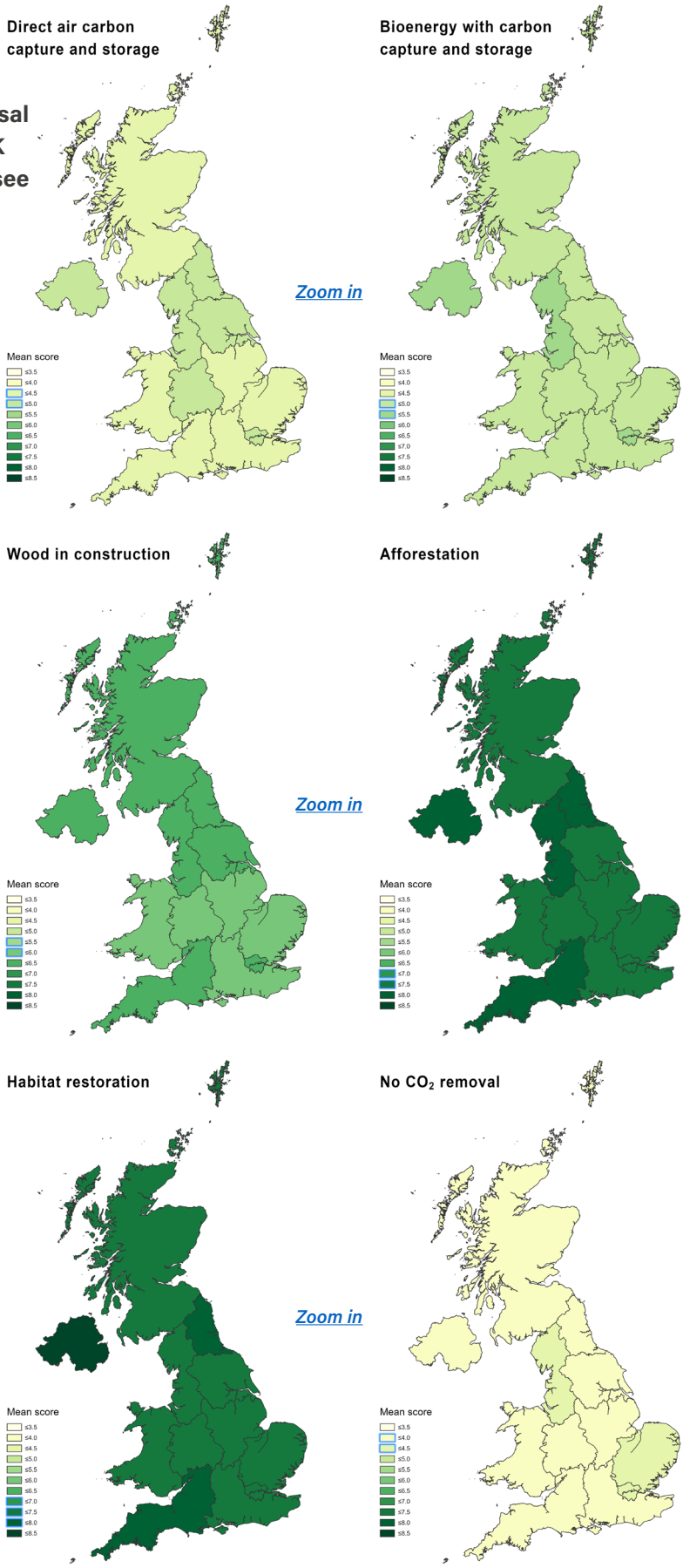
1. The public supports the inclusion of CDR in UK climate policy – but there are nuances

To set the stage for this briefing, we start by outlining the findings from our UK nationally representative multi-criteria appraisals of CDR. The analysis shows that the public supports the inclusion of CDR in UK climate policy (see Bellamy, 2022). Our findings reveal that bioenergy with carbon capture and storage (BECCS), wood in construction and afforestation are the middle performing options in public appraisals. It also shows that direct air carbon capture and storage (DACCS) and peatland restoration are the lowest and highest performing options, respectively. Clearly, some CDR methods perform better or worse than others, and resources for public engagement will need to be targeted appropriately.

Regional differences in CDR appraisals show that certain UK regions could be more or less likely to support or oppose certain CDR deployments. This means that it will be important to match different types of CDR with the places where they have the most favourable public appraisals. For example, those in the North West appraise DACCS and BECCS relatively higher than other regions, and these regions happen to be adjacent to areas of significant carbon storage potential in offshore saline aquifers. Similarly, those in Northern Ireland, the North

East and South West appraise habitat restoration relatively higher than other regions, and these areas happen to contain significant areas of peatland.

Figure 1: Public appraisal of CDR methods by UK geographical region (see Bellamy, 2022).



In deliberative workshops undertaken by CO_2RE across the UK's four jurisdictions, the majority of groups and individuals opted for scenarios with high proportions of CDR and low proportions of emissions reductions (see Cox et al., under review). This was mainly due to scepticism about emissions reductions, rather than necessarily positivity about CDR – possibly reflecting shifting climate narratives in the UK as some interest groups and media outlets become more critical of measures to meet net zero targets. Workshop participants saw emissions reductions as largely requiring individual behaviour change by 'ordinary people'. For this scenario, they expressed disempowerment, disillusionment and a general sense of fatigue at the additional pressures on citizens. By contrast, they saw CDR as placing more of the burden of responsibility onto powerful actors such as government, industry and the agricultural sector, rather than on individuals. However, there was also some caution about the specific biological techniques studied in detail (biochar, perennial biomass crops and peatland restoration). Specifically, they questioned whether these methods would be "worth it". This included scepticism about life-cycle emissions and whether they would actually be net-negative, as well as concerns about cost and about trade-offs against other policy spending objectives.

While this research provides a valuable snapshot of public appraisals of CDR, a range of factors will be important in shaping societal engagement going forward. These are outlined in the following three sections.

2. Field trials and demonstrations will play an important role in shaping public understanding and engagement with CDR

To date, public engagement with carbon removal has largely taken place at the interface between science and policy, in invited social research settings and on digital media platforms. Controversy over the promise of carbon removal as a climate strategy has (with some exceptions) been concentrated in expert forums between science, industry and organised civil society. However, as field trials proliferate, public engagement will increasingly happen in connection with specific settings where carbon removal methods are demonstrated.

Research undertaken by CO_2RE suggests that robust science and policy responses to the changing landscape of public understanding and engagement will require the following four issues to be addressed.

- **Bring research on perceptions of carbon removal closer to field trials and demonstrations.**

International research on perceptions of carbon removal has been overwhelmingly shaped by concerns about the "social acceptance" of research and development: of 49 studies we reviewed, 31 foreground this as the guiding problem for social research (see Waller, et al. 2023). This work has convincingly shown that lay individuals understand the scientific justifications for researching carbon removal, can appraise the risks associated with various methods, and that there is often qualified support for research and development across socio-demographically diverse groups. Nonetheless, many methods for studying perceptions often require that participants are distant from the practical realities of field trials. The over-emphasis on hypothetical acceptance, we suggest, leaves perceptions studies poorly equipped to understand and engage with conflicts that will inevitably emerge around real-world carbon removal projects. Research on perceptions of carbon removal could be enriched by empirical attention to how field trials create spaces in which perceptions can interact and diverge.

- **Recognise that field trials are unlikely to settle controversy over whether carbon removal can guide, or constrain, climate policy.**

Through ethnographic research we have ourselves attempted to empirically describe how researchers, in practice, turn field sites into spaces for demonstrating carbon removal methods (Waller, et al. in review b). Field work shapes not only how experiments produce evidence for decision-makers but also how field trials govern expectations about future technology deployment. We examine how field researchers navigate practical dilemmas posed by

enduring controversies over whether carbon removal is a guide for, or constraint on, climate policy. Site visits and interviews reveal practices field researchers use to demonstrate the promise of field trials for decision-making, while also distancing experiments from the consequences of technology deployment. As field trials proliferate, public contestation of carbon removal as a climate policy may increasingly centre on settings and practices of open-air demonstration. We suggest that field trials could therefore provide important opportunities for studying changing perceptions of carbon removal and detecting emerging public concerns.

- **Engage with communities to anticipate uncertainties that experiments will introduce into everyday environments.**

This point is bolstered by recent public antagonism towards some carbon removal projects in the UK. Past experiences with trials of GM crops and geoengineering research show that field sites can become public stages where local residents contest research and policy priorities. In the case of carbon removal trials, public mobilisations against them make plain the challenges of 'localising' carbon removal in a specific place. For example, ethnographic research with those involved in community protests sparked by Planetary Technology's trial of ocean alkalinity enhancement (OAE) in St Ives, UK allows us to understand the consequences carbon removal trials can have for everyday community life (Waller, et al. 2025).[1] It shows how the protests and wider practices of "shoreline demonstration" made visible nearshore-onshore entanglements not accounted for in the experiment design. Our research also enabled the Bay's communities to connect local concerns with expert debates about OAE and carbon removal. The community mobilisation exposed the weakness of the trial design for anticipating the place-specific impacts of the OAE experiment. While consultative public engagement is now often required by funders and regulators, such approaches alone will be inadequate for anticipating the place-specific impacts of experiments.

- **Consider carefully how information technologies and media used to publicise carbon removal can shape public deliberation.**

Deliberative methodologies have been central to upstream public engagement with science and technology and are prominent in the field of carbon removal. In deliberative research workshops convened by CO_2RE, we have explored how upstream deliberative participation can be framed not only by expert narratives and information but also by the devices used to orchestrate deliberative interaction (see Waller, et al. 2024). We introduced ChatGPT – a device widely credited with introducing informational unruliness into the public sphere – into workshops appraising peatland restoration, biomass crops and biochar. We invited participants to pose questions to ChatGPT and appraise the texts generated. In our research workshops there was little to indicate general value in using AI chatbots for deliberating carbon removal. However, broadening the range of devices used to publicise and deliberate carbon removal may help address perceptions of a public debate deficit in the field.

3. Greater attention should be paid to how we communicate CDR

For those engrossed in CDR debates, it is easy to forget that most people have never heard of these carbon removal strategies. Public perception of CDR is therefore particularly sensitive to framings – the ways in which policy-makers, scientists, entrepreneurs, activists, politicians, the media and others choose to organise and communicate information about it. A review of public perceptions research undertaken by CO_2RE highlights four aspects of CDR for which their framing will play a decisive role in whether, and how, it is ultimately taken forward (see Bellamy & Raimi, 2023).

1 An overview of the trial and community response can be found on the Seal Research Trust's website, with whom we collaborated to conduct this research. See: http://www.cornwallsealgroup.co.uk/2024/01/the-ocean-has-rights/

First, in lieu of other information, analogies and metaphors can shape public perceptions of how CDR methods work, as well as their benefits, risks and trade-offs. But communicators must carefully employ those that accurately convey key processes of CDR, avoid those that could create misunderstandings, and delineate how CDR both is and is not like these example phenomena. For example, describing DACCS as like "giant fans" may convey some aspects of the process and energy required for this technology, but does not convey the need to transport captured carbon. On the other hand, describing DACCS as working like "artificial trees" may convey the idea of storing carbon through this process, but doesn't instil understanding of the energy required.

Second, there is a common taxonomic split between 'nature-based' and 'technological' methods. Deliberately, tacitly or inadvertently framing certain CDR methods as 'nature-based' is well known to increase support for them, while framing others as 'engineered' decreases it. This is problematic because where the lines are drawn on what constitutes a 'nature-based' or 'engineered' method is arbitrary, privileging certain methods for no substantive reason and diverting attention away from the actual qualities of CDR methods (see Box 1 for examples from CO_2RE research).

Armed with this knowledge, communicators should acknowledge the politics of this framing and avoid the labels, instead referring to specific methods and/or using scientific terminology.

Box 1: The problem with nature-based framing

Carbon removal: avoid selective analysis

The dangers of framing CDR as 'nature-based' became particularly evident in a 2023 report from the United Nations Framework Convention on Climate Change (UNFCCC) Secretariat, which aimed to inform decision-making on CDR (see Bellamy, 2023). The report contained an assessment of the pros and cons of what it categorised as "engineered" and "land-based" CDR methods. It concluded that engineered methods are "technologically and economically unproven", "pose unknown environmental and social risks" and "do not contribute to sustainable development". For land-based methods, it concluded the opposite. The single 'con' listed for land-based methods – the impermanence of stored carbon – was in fact compounded by problems such as monitoring, reporting and verification (MRV); risks to biodiversity; release of greenhouse gases; and land-use conflicts. And the 'cons' listed for engineered methods were not foregone conclusions. Those methods could be safe, economical and sustainable if implemented well.

Carbon removal beyond the trees

In the case of forestation, the nature framing has become so ingrained that its popularity may be harming support for other CDR methods (see Cox, et al. 2025). In data collected by CO_2RE, particularly our qualitative studies, we have witnessed this effect for a wide range of different carbon removal techniques, including geological, electrochemical and biological methods, in locations around the world. Trees are perceived as natural, intuitive, providing co-benefits and acting on a more preferable timescale in a context of climate urgency. In various projects, we attempted to balance this by communicating the huge scale of tree-planting and land-use change which would be required, or by emphasising the need for permanent storage, but none of this appears to have made a difference. We should therefore be wary of policy that mispurposes the general enthusiasm for tree-planting, such as policies which support carbon forestry involving poor-quality credits or land grabs, and those which promote the false equivalence of different kinds of removals. At the same time, we would do well to appreciate the complex reasons behind public support for tree-planting, including the way that it is seen as a desire for agency in the face of a systemic problem. We should query the way in which tree-planting is often conflated with climate action, and instead focus on its other benefits, such as biodiversity support, flood prevention, air quality improvement and wellbeing.

Third, climate advocates often fear that discussion of CDR will take away from the need for emissions reductions. But these misperceptions can be corrected if communicators explain that while CDR may help reach climate goals, it can only do so on the margins of substantial emissions reductions.

Fourth, CDR methods are not simply technical objects. They are combinations of technical objects and social arrangements that work together as a single system. Early empirical work shows that the missing half of CDR communications can make all the difference in terms of public support. For example, public perception of BECCS can significantly change depending on the policy instruments chosen to incentivise it (see Bellamy, et al. 2019). Therefore, the task for CDR communicators is to not presume a particular implementation context, but to articulate a variety of potential options.

4. CDR governance matters

Social science research undertaken by CO_2RE has revealed a range of implications for how we go about CDR governance, by which we mean the societal *steering* of the methods. These include considerations around:

- the suitability of responsible innovation frameworks (i.e. innovation frameworks that anticipate impacts, reflect on framings, engage society and are responsive) for governing CDR demonstrations;
- public preferences for alternative governance scenarios for the deployment of CDR; and
- lessons for deploying socially robust novel biological CDR techniques.

Discussions about responsible innovation and carbon removal have often been subsumed within the topic of geoengineering. In relation to geoengineering controversies in the mid-2010s, UK-based approaches to responsible innovation were closely associated with the UK Research Councils, which were seen to be critical sites for decision-making. The focus on research funders reflected, in part, assumptions about the disruptive character of geoengineering techniques and the scale of deployment that would be required to have an impact on the global climate system. Such assumptions, however, apply unevenly to carbon removal methods, many of which may be deployed in ways not considered relevant to global-scale geoengineering. Work from social scientists across the GGR-D programme[2] highlights how carbon removal methods have developed within a diversity of scientific fields and around established governance conventions and protocols (see Waller, et al. in review a). While social science research is often positioned by funders as instrumental in connecting carbon removal research with climate policy-makers, social scientists also have critical roles to play in showing how field trials can distribute social responsibility for carbon removal across wider fields of environmental governance.

With regards to public preferences for alternative governance scenarios for CDR deployment, CO_2RE researchers conducted a nationally representative survey to test the impact of alternative sociotechnical systems on UK public attitudes to DACCS and OAE. Participants were randomly assigned to one of five scenario conditions, representing different forms of governance logic (top-down vs bottom-up) and market logic (planned vs liberal economy), plus one with minimal information about governance and market logic. The scenario condition significantly impacted perceptions of OAE, with participants preferring its implementation within a bottom-up, planned economy scenario, and rejecting scenarios which most closely resembled the status quo. There were no significant differences between scenarios for DACCS, suggesting that the technology may be more flexible across alternative sociotechnical arrangements. OAE aroused more negative emotions, particularly worry about impacts on ocean ecosystems, whereas DACCS aroused more hope. This suggests that different governance scenarios may lead to varying levels of societal acceptance across CDR methods.

Drawing on deliberative workshops we have undertaken across the UK's four jurisdictions, we make the following recommendations for developing and deploying socially robust novel biological CDR techniques:

- First, maximising the agency of local communities will be crucial. CDR researchers and developers should combine scientific and non-scientific sources of expertise to build trust, incorporating traditional and landowner knowledge to communicate novel biological CDR to non-experts.

2 The Greenhouse Gas Removal Demonstrators (GGR-D) programme is funded by UKRI and comprises the CO_2RE Hub and five Demonstrator projects. See: https://co2re.org/ggr-projects/

- Second, when considering deployment locations, it is crucial to consider local contexts (see Section 2) and recognise that there is no 'one-size-fits-all' approach. An 'early leader' approach, where less vulnerable locations act as early adopters to build knowledge and capacity, may help to take pressure off locations with low capacity and strained resources.
- Third, at an overarching level, we recommend regulatory precautions to guard against the potential for large-scale biological CDR deployment to absolve polluting industries from their responsibilities to mitigate their own emissions.

References

Bellamy, R. (2022). "Mapping public appraisals of carbon dioxide removal". *Global Environmental Change*, 76, 102593. https://doi.org/10.1016/j.gloenvcha.2022.102593

Bellamy, R. (2023). "Carbon removal: Avoid selective analysis". *Nature*, 619, 34. https://www.nature.com/articles/d41586-023-02131-5

Bellamy, R. and Raimi, K. (2023). "Communicating carbon removal". *Frontiers in Climate*, 5, 120538. https://doi.org/10.3389/fclim.2023.1205388

Cox, E., Bellamy, R. and Waller, L. (2024). "Public attitudes and emotions toward novel carbon removal methods in alternative sociotechnical scenarios". *Environmental Research Letters*, 19, 084026. https://iopscience.iop.org/article/10.1088/1748-9326/ad5dd0

Cox, E., Low, S., Baum, C., Fritz, L., Waller, L., Spence, E., Pidgeon, N. and Bellamy, R. (2025). "Carbon removal beyond the trees". *Communications Earth & Environment*, 6, 253. https://doi.org/10.1038/s43247-025-02226-z

Cox, E., Waller, L., Palmer, J., Bellamy, R. (2025). "Carbon removal support is tempered by caution over some biological methods". *Communications Earth and Environment*, 6, 711. https://www.nature.com/articles/s43247-025-02654-x

Waller, L., Cox, E. and Bellamy, R. (2023). "Carbon removal demonstrations and problems of public perception". WIREs Climate Change, e857. https://doi.org/10.1002/wcc.857

Waller, L., Moats, D., Cox, E. and Bellamy, R. (2024). "Questionable devices: Applying a large language model to deliberate carbon removal". *Environmental Science & Policy*, 162, 103940. https://doi.org/10.1016/j.envsci.2024.103940

Waller, L., Cox, E., Binner, A., Cantillo, T., Everett, R., Henwood, K., Ingram, J., Morris, C., O'Sullivan, K., Pidgeon, N., Price, C., Reed, M.S., Roberts, E., Silvestri, A. and Bellamy, R. (under review a). "Responsible research and innovation of carbon removal in the UK: strategies for open-air trials". *Frontiers in Climate*.

Waller, L., Cox, E. and Bellamy, R. (under review b). "Promising fieldwork: carbon removal field trials and the governance of expectations". *Science, Technology and Human Values*.

Waller, L., Cox, E. and Bellamy, R. (2025). "Shoreline demos: the contested place of the public in a marine carbon removal trial". *Environment and Planning E: Nature and Space*. https://journals.sagepub.com/doi/10.1177/25148486251380158

Acknowledgements

This policy brief is based upon Bellamy (2022); Bellamy (2023); Bellamy & Raimi (2023); Waller, et al. (2023); Cox, et al. (2024); Waller, et al. (2024); Cox, et al. (2025); Cox, et al. (under review); Waller, et al. (under review a); Waller, et al. (under review b); and Waller, et al. (2025). The authors are grateful to Caterina Brandmayr, Helen Bunting and Alyssa Gilbert for their valuable comments.

CO$_2$RE THE GREENHOUSE GAS REMOVAL HUB

www.co2re.org

Funded through the UKRI SPF Greenhouse Gas Removal Demonstrators (GGR-D) Programme, CO$_2$RE co-ordinates the Programme and conducts solutions-led research to evaluate a balanced portfolio of economically, socially and environmentally scalable Greenhouse Gas Removal options, with associated policy design, engagement and outreach.

This paper is part of a series of briefings presenting findings and recommendations from different areas of CO$_2$RE's research. Read more at **www.co2re.org/publications-key-reports-briefings**.

UK Research and Innovation

CO$_2$RE , The Greenhouse Gas Removal Hub is funded by UK Research and Innovation grant reference NE/V013106/1.